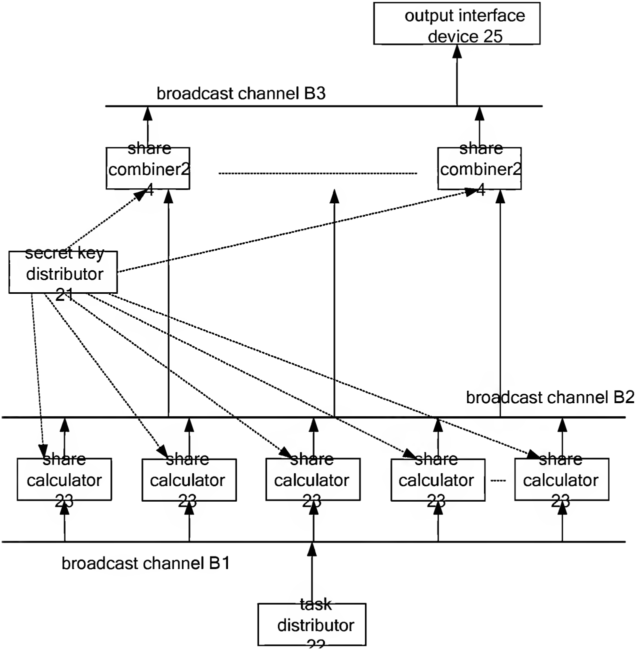
Abstract

The present invention relates to a digital signature system and method. The system comprises a task distributor, k calculators, m combiners and a sub-secret-key distributor. The processing of distributing sub-secret-keys comprises the step of: the sub-secret-key distributor expressing a private key d as a sum of t sub-secret-keys d_{ji} and one sub-secret-key c_a , and t < k; the distributor distributing k×I random numbers d_{ji} into i d_{ji} per calculator and sends them to k calculators, forming C_k^t equivalent combination sets by extending C_k^t combinations, obtaining the equation combination representations of a set of c_a and the c_a thereof, acquiring m groups by searching based on the combiner security condition and sending them to m combiners for pre-storage. The processing of generating a digital signature comprises the steps of: the task distributor sending the value of a signature, M, to k calculators, the calculators computing ascending power $M^{d_{ji}}$; sending i computation results to combiners and the combiners comparing them with pre-stored equation combination representations of c_a, finding out a matched equation combination representation and obtaining corresponding c_a, and based on R obtained through multiplying $M^{d_{ji}}$, then computing M^{c_a}, finally obtaining a digital signature $S=M^d$.

Drawing for Abstract



Claims

1. A secure digital signature system, comprising:

at least one online task distributor, k online secret share calculators, m online secret share combiners and an offline sub-secret-key distributor; wherein said online task distributor is connected to said k secret share calculators through a first broadcast channel, said k secret share calculators are connected to said m secret share combiners through a second broadcast channel, said offline sub-secret-key distributor is connected to said k secret share calculators and m secret share combiners during system initialization or configuration process; wherein k and m are positive integers, the system of Claim 1, further comprising an independent output interface device connected to m secret share combiners through a third broadcast channel.

2. The secure digital signature system of Claim 1, further comprising an independent output interface device connected to m secret share combiners through a third broadcast channel.

3. The secure digital signature system of Claim 1, wherein an output interface device that is connected to said m secret share combiners through the first broadcast channel is set in said online task distributor.

4. The secure digital signature system of Claim 1, 2 or 3, wherein all of at least one online task distributor, k online secret share calculators, m online secret share combiners and the offline sub-secret-key distributor are general-purpose computers or servers.

5. The secure digital signature system of Claim 1, 2 or 3, wherein the first broadcast channel, the second broadcast channel and the third broadcast channel are channels connected physically or independent channels not connected at all.

6. A secure digital signature method, comprising the steps of distributing a sub-secret-key and computing a digital signature, wherein

said distributing a sub-secret-key comprises the steps of:

A. setting a secure digital signature system which comprises an online task distributor, k online secret share calculators, m online secret share combiners, broadcast channels and an offline sub-secret-key distributor, wherein k and m are positive integers;

B. said offline sub-secret-key distributor expressing the stored private key for digital signature d as a sum of t first sub-secret-keys d_{ji} and a second sub-secret-key c_a; wherein d, t, c, j and i all are positive integers, t < k, j is the machine number of the j^{th} secret share calculator, i is the secret key number inside the secret share calculators, j = 1, 2 … k, and i = 1, 2 … I;

C. said offline sub-secret-key distributor generating k×I random numbers as the first sub-secret-keys d_{ji} and distributing them to k secret share calculators so that each secret share calculator stores I first sub-secret-keys d_{ji}; based on the additive formula in Step B, obtaining a group of second sub-secret-keys c_a and their equation combination representations by subtracting; and then obtaining their equivalent combination sets from the equation combination representations and putting them into a large group;

D. according to combiner security condition, said offline sub-secret-key distributor searching for all equivalent combination sets in said large group and taking one combination from each equivalent combination set as a representative; putting all representatives of equivalent combination sets into m subgroups, obtaining the second sub-secret-keys c_a and their equation combination representations of the m subgroups;

E. said offline sub-secret-key distributor sending second sub-secret-keys c_a and their equation combination representations of the m subgroups to m secret share combiners for pre-storage;

said computing of a digital signature comprises the steps of:

F. said online task distributor sending the hash value M to be signed to said k secret share calculators via the first broadcast channel through broadcasting data packets;

G. t or more than t secret share calculators among k secret share calculators computing ascending power $M^{d_{ji}}$ based on the received value M; sending secret share calculators number j, the hash value M to be signed, the secret key number i inside the machine and I computation results $M^{d_{ji}}$ to m secret share combiners via the second broadcast channel through broadcasting data packets;

H. said m secret share combiners comparing the received results with pre-stored equivalent combination representations of the second sub-secret-keys c_a and finding out a matching equivalent combination representation and the corresponding second

sub-secret-key c_a, and then multiplying ascending power computation results of t secret share calculators matching to the combination to obtain R; finally, computing M^{C_a} based on the found c_a, and multiplying M^{C_a} with R to obtain a digital signature $S=M^d$;

7. The secure digital signature method of Claim 6, wherein Step A further comprising: setting an arbitrary number to said online task distributor, setting different numbers to k secret share calculators respectively, setting different numbers to m secret share combiners respectively and setting an initial value for t.

8. The secure digital signature method of Claim 6, wherein the number of bits in d_{ji} is maximally one fourth of that in c_a in Step B.

9. The secure digital signature method of Claim 6, wherein Step C further comprises:

c1. said offline sub-secret-key distributor generating k×I random numbers smaller than d/t as first sub-secret-keys d_{ji} and sending them to k secret share calculators with a mode accepted by administration;

c2. said offline sub-secret-key distributor solving all machine combinations from combination formula C_k^t, extending each machine combination to solve its equivalent combination set; wherein each equivalent combination set has I^t combinations and each combination has t items consisted of two digits j i;

c3. putting all equivalent combination sets into a big group.

10. The secure digital signature method of Claim 9, wherein the equivalent combination sets are sets of combinations with a same machine number of secret share calculator.

11. The secure digital signature method of Claim 6, wherein Step D further comprises:

d1. sorting the equivalent combination sets in the big group randomly, sorting the combinations in each equivalent combination set randomly, and setting an empty subgroup as the current subgroup;

d2. taking out an equivalent combination set based on the sorting order from the big group, taking out a combination based on the sorting order from the equivalent combination set, verifying whether the combination meets the combiner security condition in the current subgroup, putting the combination into the subgroup and discarding the equivalent

combination set if yes, and otherwise, moving the combination back into the equivalent combination set;

d3. performing Step d2 till the operation for the combinations in the equivalent combination set are processed are performed, and moving the esc back to the big group if no combination can be put into the current subgroup;

d4. taking out another equivalent combination set based on the sorting order from the big group and performing Steps d2 and d3;

d5. checking whether there is an equivalent combination set in the big group, and reestablishing an empty subgroup as the current subgroup and performing Steps d2, d3 and d4 till there is no equivalent combination set in the big group if yes;

d6. counting the number m of the subgroups in which there is a combination and sending the combinations in the groups to m secret share combiners correspondingly.

12. The secure digital signature method of Claim 10, wherein Step d6 further comprises a step of adding redundant combinations satisfying the combiner security conditions into the m subgroups, respectively.

13. The secure digital signature method of Claim 6, 11 or 12, wherein the combiner security condition is an equation obtained by linear combination of any two equations in the subgroup, the number of variables of the equation is greater than t.

14. The secure digital signature method of Claim 6, wherein said offline secret key distributor sends second sub-secret-keys c_a and their equation combination representations of the m subgroups to m secret share combiners with a mode accepted by administration in Step E.

15. The secure digital signature method of Claim 6, wherein said offline secret key distributor is in a physical isolation state or a shut down state after the process of distributing sub-secret-key has been completed through Steps A, B, C, D and E.

16. The secure digital signature method of Claim 6, wherein Step F further comprises:

f1. said online task distributor receiving a digital signature task and performing a security examination and check;

f2. said online task distributor defining a task number that is unique for said task in a preset duration;

f3. said online task distributor broadcasting the online task distributor number, the task number, the hash value M to be signed to the first broadcast channel through broadcasting data packets;

said Step G further comprising:

g1. t or more than t secret share calculators sending an acknowledgement to said online task distributor after having received said broadcasting data packets;

g2. said t or more than t secret share calculators checking uniqueness of said task; if it is determined as a new task, making said ascending power computation;

g3. said t or more than t secret share calculators broadcasting the online task distributor number, the task number and the secret share calculators number j with said task, said hash value M to be signed, I secret key numbers and corresponding I computation results $M^{d_{ji}}$ to the second broadcast channel through broadcasting data packets;

said Step H further comprising:

h1. the secret share combiners which have received the data packets putting data packets with the same task distributor number and the same task number into a group;

h2. said secret share combiners finding out at least t data packets, and from them finding out an equation combination representation that is matched with said pre-stored equation combination representation, and obtaining corresponding second sub-secret-keys c_a.

17. The secure digital signature method of Claim 6 or 16, wherein the processing of computing digital signature is completed through sequentially performing Steps F, G and H.

18. The secure digital signature method of Claim 6,

further comprising Step I after Step H, said Step I comprising: said online secret share combiners sending the digital signature $S=M^d$, the task distributor number and the task number to an online output interface device through broadcasting data packets; and then said output interface device verifying the result of signature with the public key; if the digital certificate is correct, ending the issuing of the digital signature; if the digital certificate is

incorrect, implementing an error processing or a warning processing.

19. The secure digital signature method of Claim 18, wherein online secret share combiners send the broadcasting data packets to an independent online output interface device through the third broadcast channel in Step I.

20. The secure digital signature method of Claim 18, wherein online secret share combiners send the broadcasting data packets to an online output interface device which is set in the task distributor through the first broadcast channel in Step I.

Specification

Digital Signature System and Method

Field of the Technology

The present invention relates to network communication security technology, more specifically to a system and method with intrusion tolerance ability which can ensure the safety of digital signatures.

Background of the Invention

Digital signature nowadays is a basic technology in the field of network communication security. Digital signature uses Asymmetric Cryptography Algorithm to assure that others may verify the digital signature but cannot personate it. The most popular asymmetric algorithms are RSA, DSA and Elliptical Curve Algorithm etc. At present, many digital signature systems are based on RSA (Ron Rivest, Adi Shamir and Len Adleman Algorithm) algorithm.

The asymmetric algorithm is that the reverse computation parameter cannot be derived from the known computation parameters, i.e. while the computation procedure is known, yet it has no computation ability to do reverse computation. The asymmetric algorithm is publicized, everyone can select his own parameters, and different parameters will result in different constituted transformation functions. One may select a group of parameters, some of them used for reverse computation are called secret parameters, technically called secret key or private key; the others used for computation are called public parameters or public key.

Implementation of the digital signature is based on the asymmetric algorithm. On the one hand, the self-possessed secret parameter-private key is protected, which will assure that no one can forge the digital signature; on the other hand, by publicizing what could be put to publicity-the public key, verification of the signature could be carried out for certain people. In fact, deriving secret parameters from public parameters are computationally infeasible theoretically.

First of all, digital signature guarantees the security of network communication and interaction, and it ensures that the counterpart of the communication is authentic and that it is yourself that is on line; at the same time digital signature can be used as a tool for signing electronic documents in order to protect the self-possessed documents and signatures. Today, in

many countries, digital signature has already been considered the same as manual signature, and both of them have the same legal effect.

Digital signature algorithms can also be used for negotiation of secret parameters. Suppose user A needs to communicate with user B secretly, then, user A defines secret parameters and encrypts them with user B's public key. By this means, only user B can decrypt the encrypted secret parameters, since only user B knows his own private key.

Besides, digital signature can also be used in cases where confidentiality£¬ authentication or non-repudiation is required.

The Public Key Infrastructure (PKI) that has been popular worldwide is a kind of application for digital signature. PKI is a vital infrastructure for a digital society as the importance of the electricity infrastructure for the industrial society.

To ensure security and speed of digital signatures, before signing, the content to be signed has to be hashed using a message digest function to get a hashed value, sometimes called digest value, M, and then the signature value will be obtained by encrypting the digest value with the private key. When verifying a signature, first a hash computation is made and then the public key decrypts the signature value; then the obtained result is compared with the above hashed result, if they are equal to each other, the signature is correct, otherwise the verification cannot be passed.

Nevertheless, suppose that user A has a private key and a public key, and there is an attacker B who regenerates a private key and a public key and replaces user A's public key with his own public key (the attacker B's public key).In this case, encrypted messages sent to user A by his friend will only be decrypted by attacker B, for user A does not know the corresponding private key of the forged public key of attacker B. At this time, it is highly demanded to have a Certificate Authority (CA) to verify which public key belongs to user A or to prove which public key does not belong to user A.

CA has a longer private key than that of the common users, i.e. the CA private key is more secure, and the CA public key is well-known by various ways publicly. Thus, every user can verify which is signed and issued by CA. When user's identity is attached with the user's public key and signed by CA, the user gets an electronic certificate, which proves the identity of the legitimate owner of the public key. Further more, everyone can verify a digital certificate, but no one can forge a digital certificate.

At present, the electronic certificate is the most pivotal part of PKI, while CA is the key unit

in PKI. With the help of the electronic certificate, security of a network, such as confidentiality, integrity, non-repudiation etc, can be solved effectively.

Security based on PKI eventually will be focused on the security of the CA's private key. Once the CA's private key is compromised, all certificates issued by the CA must be revoked and the network security controlled by the CA will be compromised. Along with the increasing of various means of network attacks, system vulnerabilities constantly be discovered, so it becomes a crucial topic of modern network security researches to insure security of online digital signature service.

For RSA, secret-key usually is noted as d that can be an integer as long as 2048 bits. Generally speaking, a private key with 1024 bits in length is enough to assure security, but for CA's, with the length of 2048 bits or even longer is recommended. The RSA uses the computation of modular exponentiation of a number N i.e. calculating expression $M^d \bmod N$, the computation is necessary for a digital signature. When the public key is publicized, protecting the integer d is to protect the private key.

The purposes of a secure digital signature is to fulfill signing but without compromising the private key. According to this subject, many theoretical researches have been carried out in the world, while some of the theories and methods are too difficult to implement due to the complexity. On the other hand, present development of PKI is focused on producing compatible digital signature products, but little development has made on aspect of secure signature with intrusion tolerance ability. So-called intrusion tolerance is relative to the intrusion detection to guarantee CA security; that is, even when part of a system has been attacked or occupied, secret information of the CA system will not be compromised.

In summary, PKI is based on public key algorithm, and CA is a trusted center of a domain in a PKI system. Communication and authentication between devices or individuals on a network depends on a digital certificate signed and issued by a CA.A digital certificate is data obtained by attaching a public key to the personal identity and then signed with the private key of a CA. When one side of a communicator wants to verify the identity of the other side, there are two steps: first, verifying whether the signature of the certificate of the other side is correct or not, for the signature can only be produced by the CA private key; and then verifying whether the other side has the private key corresponding to the public key in the certificate. If these two steps are performed successfully, then the identity of the other side is determined and trustworthy.

Therefore, the CA private key is the core part of CA security. So to protect it from

compromising is the foundation of the security of the entire CA domain. In general, CA has to be an online network device, especially the one that gets direct connection with users to provide corresponding certificate services, thus it is unavoidable to be attacked. When a hacker attacked a CA successfully, he might acquire internal resource of the CA, consequently the CA private key, and this would cause fatal damage to the PKI system. Meanwhile as a precaution, it should be assured that employee working for PKI who has got entire control of some components of a CA system cannot get the CA private key either.

In the following paragraphs, suppose that a digital signature is equivalent to implementing expression M^d mod N, wherein d is a private key, and several existing methods for security digital signature are described.

Reference to Fig.1, this is a prototype system diagram of ITTC project at US Stanford University. The system implements intrusion tolerance through threshold cryptography technology. There are clients, servers and an administrator in the system. The Web Server of the clients refers to the web server that requests signatures and CA is the certificate authority. The servers include multiple share-servers, called as share calculators or share operators, which are responsible for producing the secure digital signatures, as the share-server 1 to share-server 3 in Fig.1. The administrator is an optional device used to manage the share servers. Features of the scheme are simple configuration and high security, in this system a single layer structure with multiple share-servers is used.

Principle for the system to achieve security is to first divide a private key d into a sum of t numbers: $d=d_1+d_2+\ldots+d_t$, and then each number d_i is allocated to every share-server accordingly. When a signature is necessary, the client, a web or a CA, sends the information of a HASH value M that needs to be signed to every share-server; and then every share-server returns the computation result $M_i = M^{d_i}$ to the client, a web or a CA, accordingly. The client then makes multiplication:

$$S = \prod_{i=1}^{t} M^{d_i} = M^{\sum_{i=1}^{t} d_i} = M^d$$

And the result needed is obtained.

To implement redundancy, multiple groups of the equations can be further used to implement redundancy configuration, i.e. taking several groups of the d division randomly, such as:

First group: $d=d_{11}+d_{12}+\ldots+d_{1t}$;

Second group: $d=d_{21}+d_{22}+\ldots+d_{2t}$;

.... ,

Then, the numbers of multiple groups (d_{ij}) are allocated to different share-servers in the way that every share-server can obtain multiple d_{ij}, but can only obtain one data of the same group, for example share-server 1 obtains d_{11} from the first group and d_{23} from the second group. For instance, suppose there are four share-servers and t = 3, the allocation can be as in the following table:

Share-server 1	Share-server 2	Share-server 3	Share-server 4
d_{11}	d_{12}	d_{13}	d_{13}
d_{23}	d_{21}	d_{22}	d_{23}

When a client, a Web or a CA, wants to compute the signature, the client selects t perfect share-servers and tells the share-servers which group of the data or parameters should be used, and then the share-servers can compute the according signature.

Advantages of this scheme are obvious, but the disadvantages are as follows.

1. It is difficult to allocate and manage sub-secret-keys. Whenever adding a share-server, the sub-secret-keys must be allocated for every online share-server and also the adding of the new share-server must be known by clients.

2. When there are many share-servers, the storage capacity for sub-secret-keys will be rapidly increased. Suppose the total number of share-servers is k, and the required number of the perfect share-servers is t, then the number of stored sub-secret-keys for each share-server is at least C_k^{t-1} , wherein C represents combination. When k = 10 and t = 3, each share-server has to store 45 sub-secret-keys.

3. There is a synchronization problem that must be solved at first. Before computation, the client must select t share-servers, then find out data groups matching to the t share-servers and inform them; once one of the t share-servers has been destroyed, the above selecting procedure must be repeated.

4. It is difficult for the client (CA or Web server) to remember every change made by the share-servers, it is not easy to manage or extent, especially when the client is online, it is more

difficult to extend so that updating the data of client is necessary whenever the share-servers' parameters change.

Victor Shoup at IBM Research Zurich Institute has released an article titled "Practical Threshold Signatures" on Europe Cryptography Annual Meeting in the Year 2000, what the article introduces is a theoretical scheme on digital signature. The scheme employs RSA algorithm with strong prime, primes kept in secret are p = 2p' + 1 and q = 2q' + 1.All interpolation equations are made in the ring of mod m = p'q'. Since M^{4m} mod N is equal to 1, when computation is separate, one more square operation is needed. This is performed by the Combiner that takes a square operation to each result respectively, to obtain $M^{4\Delta(gm+d)}$,wherein $\triangle=(k!)^2$ and g is an integer. In this scheme, CA is performed by the combiner, so the synchronization problem before computation is eliminated, but it increases computation difficulties and decreases computation performance of the combiner. For example, the combiner must compute following formula:

$$W = y_{i_1}^{2\lambda c_{i_1}} y_{i_2}^{2\lambda c_{i_2}} \dots y_{i_t}^{2\lambda c_{i_t}}$$

wherein y_i is the computation result of each share-server and λ=k! .

It can be seen that the features and disadvantages of this scheme lie in:

1. It is still a single layer sharing structure consisted of share-servers, the combiner does not store any secret information, so any device can fulfill the combination work.

2. Computation volume of the combiner is approximate to or equal to that of signing for t times, this computation volume is far more than that of the share-servers, so even if the algorithm can be implemented, the scheme cannot be used in practical signing.

3. It is required to use strong primes, which will bring about limitation for some applications.

4. It is only described theoretically that other devices will not be affected when increasing or deleting a share-server; yet, the description only provides mathematical formula with no explanation on implementation or system structure.

Yair Frankel et al in CertCo Company in New York has brought forward a scheme but without implementation diagram or any details of the system. In this scheme, it is proposed that polynomial coefficients a_i is in {0, L,…,$2L^3N^{2+e}t$}, wherein L=k!, and x_i belongs to [1,2,…,k-1].Since all $f(x_i)$ can be divided by L, so b_i computation is without reverse operation and can be made in the integer domain. The scheme may apply the general RSA algorithm without the requirement of strong

prime. Nevertheless, as parameter selection is greatly limited, so algorithm principle and proving of security becomes complicated. For example, the combiner must compute following formula:

From the mathematical description, the scheme has the following disadvantages:

1. A secret-key is shared equally, that is, the share is a single layer structure.

2. Selection of parameters is limited and prove of security is complicated, so possibility of loophole occurring is increased.

3. The synchronization problem exists and if taking away synchronization, computation volume of the combiner will be greatly increased.

The schemes of IBM Research – Zurich Institute and CertCo Company are all based on the Shamir scheme of sharing secret-key using LaGrange interpolation equation. In the original Shamir secret sharing scheme, a secret-key can be generated by taking t shared secret-keys randomly. But in the original Shamir scheme, the secret-key has to be recovered first and this is unexpected for any scheme, for above all the signature security must assure that it is impossible to recover the secret-key in any device.

Basic principle of Shamir scheme of sharing secret-key is as follows:

Give a polynomial $f(x)=\sum_{i=0}^{t-1} a_i x_i$, with Lagrange interpolation formula there is:

$$f(x)=\sum_{i=1}^{t}(f(x_i)\prod_{j=1,t}^{j\neq i}\frac{x-x_j}{x_i-x_j}) \qquad (1)$$

Select t individual items of x_i and $f(x_i)$, it can be obtained that:

$$a_0=f(0)=\sum_{i=1}^{t}(f(x_i)\prod_{j=1,t}^{j\neq i}\frac{-x_j}{x_i-x_j}) \qquad (2)$$

a_0 can be set as a secret-key, in this case the signature computation of a hash value M is:

$$M^d=M^{f(0)}=\prod_{i=1}^{t}M^{f(x_i)\prod_{j=1,t}^{j\neq i}\frac{-x_j}{x_i-x_j}}=\prod_{i=1}^{t}M^{b_i} \qquad (3)$$

wherein $b_i = f(x_i) * c_i = f(x_i) \prod_{j=1,t}^{j \neq i} \frac{-x_j}{x_i - x_j}$ (4)

Therefore, secret-key d can be divided into k share-servers, with k≥t. Each share-server computes M^{b_i}, then a combiner multiplies computation results of every share-server to obtain the M^d. In this case, any share-server does not leak the secret-key d. Since there are division operations in formula (4), it is easy to be considered to find a domain or ring Z_v for the computation. Here, it must be satisfied that v is a prime number, or v and the determinant of t order Vandermonde array consisted of x_i are relative primes.

In general situation, computing M^{b_i} separately will bring a consequence that multiplication $\prod_{i=1}^{t} M^{b_i} = M^{d+wv}$ is needed. About how to take away the affection of v, many people thinks about the $\Phi(N)$ for the reason that $M^{\Phi(N)}=1$.When $v=\Phi(N)$ is taken, selection of x_i is greatly limited by the above condition. Furthermore, when an element O and its $\Phi(N)$ inverse O^{-1} are known, the $\Phi(N)$ can be obtained, so it is obviously unsafe.

Therefore, theoretically the above schemes have evident disadvantages and there are a lot of problems that need solving before the practical application.

Summary of the Invention

An object of the invention is to provide a secure digital signature system and the secure issuing method thereof, which are a secure signature issuing system and method with intrusion tolerance ability. Based on the present CA security principle, the system and method can solve the pre-synchronization problem, and satisfy online CA security requirement. With this system and method, even if a part of key components in system are conspiracy attacked, it is assured that system secret will not be compromised, meanwhile, the system can provide continuous service even when some components are fault or took out.

In the secure digital signature method according to the present invention, CA is based on RSA algorithm. The method at least should satisfy the following requirements.

1. Even when an attacker has attacked or occupied several components of a system, or when conspiracy attack is made by some key components of the system, the attacker cannot disclose the private key; and there are relatively fewer key components used in the system and working tasks of the key components are basically equilibrium.

2. The system is easy to extend and adding a share calculator as demanded does not affect normal operation of the system.

3. The system is easy to manage when operation. The management includes addition, deletion and update of service hardware or software, and the system management does not affect normal operation of system.

4. When one or several devices are damaged, normal service will not be affected.

5. When a secret share calculator is damaged, efficiency of the system will not decrease too much, and the task distributor doesn't need any information about task executors.

6. At the beginning of a computation, any device doesn't need to know its cooperators, so it is unnecessary to have a mechanism to define a cooperation group (pre-synchronization).

7. Algorithm and principle of the system should be rather simple.

8. Efficiency of the system should be at the same level as the conventional system.

The object of the invention is achieved by a secure digital signature system comprising:

at least one online task distributor, k online secret share calculators, m online secret share combiners and an offline sub-secret-key distributor; wherein said online task distributor is connected to said k secret share calculators through a first broadcast channel, said k secret share calculators are connected to said m secret share combiners through a second broadcast channel, said offline sub-secret-key distributor is connected to said k secret share calculators and m secret share combiners during system initialization or configuration process; wherein k and m are positive integers. The system of Claim 1, further comprising an independent output interface device connected to m secret share combiners through a third broadcast channel.

The system further comprises an independent output interface device connected to m secret share combiners through a third broadcast channel.

An output interface device that is connected to said m secret share combiners through the first broadcast channel is set in said online task distributor.

All of at least one online task distributor, k online secret share calculators, m online secret share combiners and the offline sub-secret-key distributor are general-purpose

computers or servers.

The first broadcast channel, the second broadcast channel and the third broadcast channel are channels connected physically or independent channels not connected at all.

Additionally, the above object is achieved by a secure digital signature method, comprising the steps of distributing sub-secret-key and computing digital signature.

Wherein distributing sub-secret-key comprises:

A. setting a secure digital signature system which comprises an online task distributor, k online secret share calculators, m online secret share combiners, broadcast channels and an offline sub-secret-key distributor, wherein k and m are positive integers;

B. said offline sub-secret-key distributor expressing the stored private key for digital signature d as a sum of t first sub-secret-keys d_{ji} and a second sub-secret-key c_a; wherein d, t, c, j and i all are positive integers, $t < k$, j is the machine number of the j^{th} secret share calculator, i is the secret key number inside the secret share calculators, $j = 1, 2 \ldots k$, and $i = 1, 2 \ldots I$;

C. said offline sub-secret-key distributor generating $k \times I$ random numbers as the first sub-secret-keys d_{ji} and distributing them to k secret share calculators so that each secret share calculator stores I first sub-secret-keys d_{ji}; based on the additive formula in step B, obtaining a group of second sub-secret-keys c_a and their equation combination representations by subtracting; and then obtaining their equivalent combination sets from the equation combination representations and putting them into a large group;

D. according to combiner security condition, said offline sub-secret-key distributor searching for all equivalent combination sets in said large group and taking one combination from each equivalent combination set as a representative; putting all representatives of equivalent combination sets into m subgroups, obtaining the second sub-secret-keys c_a and their equation combination representations of the m subgroups;

E. said offline sub-secret-key distributor sending second sub-secret-keys c_a and their equation combination representations of the m subgroups to m secret share combiners for pre-storage;

The process of computing digital signature comprises:

F. said online task distributor sending the hash value M to be signed to said k secret share calculators via the first broadcast channel through broadcasting data packets;

G. t or more than t secret share calculators among k secret share calculators computing ascending power $M^{d_{ji}}$ based on the received value M; sending secret share calculators number j, the hash value M to be signed, the secret key number i inside the machine and I computation results $M^{d_{ji}}$ to m secret share combiners via the second broadcast channel through broadcasting data packets;

H. said m secret share combiners comparing the received results with pre-stored equivalent combination representations of the second sub-secret-keys c_a and finding out a matching equivalent combination representation and the corresponding second sub-secret-key c_a, and then multiplying ascending power computation results of t secret share calculators matching to the combination to obtain R; finally, computing M^{C_a} based on the found c_a, and multiplying M^{C_a} with R to obtain a digital signature $S=M^d$;

Step A further comprising: setting an arbitrary number to said online task distributor, setting different numbers to k secret share calculators respectively, setting different numbers to m secret share combiners respectively and setting an initial value for t.

The number of bits in d_{ji} is maximally one fourth of that in c_a in Step B.

c1. said offline sub-secret-key distributor generating k×I random numbers smaller than d/t as first sub-secret-keys d_{ji} and sending them to k secret share calculators with a mode accepted by administration;

c2. said offline sub-secret-key distributor solving all machine combinations from combination formula C_k^t, extending each machine combination to solve its equivalent combination set; wherein each equivalent combination set has I^t combinations and each combination has t items consisted of two digits j i;

c3. putting all equivalent combination sets into a big group.

The equivalent combination sets are sets of combinations with a same machine number of secret share calculator.

Said Step D further comprises:

d1. sorting the equivalent combination sets in the big group randomly, sorting the combinations in each equivalent combination set randomly, and setting an empty subgroup as the current subgroup;

d2. taking out an equivalent combination set based on the sorting order from the big group, taking out a combination based on the sorting order from the equivalent combination set, verifying whether the combination meets the combiner security condition in the current subgroup, putting the combination into the subgroup and discarding the equivalent combination set if yes, and otherwise, moving the combination back into the equivalent combination set;

d3. performing Step d2 till the operation for the combinations in the equivalent combination set are processed are performed, and moving the esc back to the big group if no combination can be put into the current subgroup;

d4. taking out another equivalent combination set based on the sorting order from the big group and performing Steps d2 and d3;

d5. checking whether there is an equivalent combination set in the big group, and reestablishing an empty subgroup as the current subgroup and performing Steps d2, d3 and d4 till there is no equivalent combination set in the big group if yes;

d6. counting the number m of the subgroups in which there is a combination and sending the combinations in the groups to m secret share combiners correspondingly.

Said Step d6 further comprises a step of adding redundant combinations satisfying the combiner security conditions into the m subgroups, respectively.

The combiner security condition is an equation obtained by linear combination of any two equations in the subgroup, the number of variables of the equation is greater than t.

Said offline secret key distributor sends second sub-secret-keys c_a and their equation combination representations of the m subgroups to m secret share combiners with a mode accepted by administration in Step E.

Said offline secret key distributor is in a physical isolation state or a shut down state after the process of distributing sub-secret-key has been completed through Steps A, B, C, D and E.

Step F further comprises:

f1. said online task distributor receiving a digital signature task and performing a security examination and check;

f2. said online task distributor defining a task number that is unique for said task in a preset duration;

f3. said online task distributor broadcasting the online task distributor number, the task number, the hash value M to be signed to the first broadcast channel through broadcasting data packets;

Step G further comprises:

g1. t or more than t secret share calculators sending an acknowledgement to said online task distributor after having received said broadcasting data packets;

g2. said t or more than t secret share calculators checking uniqueness of said task; if it is determined as a new task, making said ascending power computation;

g3. said t or more than t secret share calculators broadcasting the online task distributor number, the task number and the secret share calculators number j with said task, said hash value M to be signed, I secret key numbers and corresponding I computation results $M^{d_{ji}}$ to the second broadcast channel through broadcasting data packets;

Step H further comprises:

h1. the secret share combiners which have received the data packets putting data packets with the same task distributor number and the same task number into a group;

h2. said secret share combiners finding out at least t data packets, and from them finding out an equation combination representation that is matched with said pre-stored equation combination representation, and obtaining corresponding second sub-secret-keys c_a.

The processing of computing digital signature is completed through sequentially performing Steps F, G and H.

The method further comprises Step I after Step H, said Step I comprising: said online secret share combiners sending the digital signature $S=M^d$, the task distributor number and the task number to an online output interface device through broadcasting data packets; and then said output interface device verifying the result of signature with the public key; if the

digital certificate is correct, ending the issuing of the digital signature; if the digital certificate is incorrect, implementing an error processing or a warning processing.

Online secret share combiners send the broadcasting data packets to an independent online output interface device through the third broadcast channel in Step I.

Online secret share combiners send the broadcasting data packets to an online output interface device which is set in the task distributor through the first broadcast channel in Step I.

The secure digital signature system and method according to the invention is based on RSA algorithm. Through secret-key share with a two layer asymmetric structure, the system management and implementation difficulties mentioned in the background section are overcome, thus the object of the invention is achieved.

The method and system according to the invention have the following characteristics:

1. The online task distributor can broadcast a digital signature task without selecting secret share calculators and specifying sub-secret-keys, so when system is updating, the online task distributor will not be affected, and when a secret share calculator is damaged suddenly, execution time for broadcasting a task will not be affected too.

2. When adding a secret share calculator, it is necessary only to generate a sub-secret-keys. The offline sub-secret-key distributor can make equation combination according to the number of the newly added secret share calculator and the numbers of existing secret share calculators, compute the corresponding second sub-secret-key c_a, and then add the new equation combination representation and c_a to the secret share combiner in a way accepted by administration. The adding will not affect the system normal operation.

3. When taking away a secret share calculator, shutting down the device is enough; for efficiency reason, equation combination representation including the secret share calculator number and corresponding c_a can be deleted.

4. The invention has the intrusion tolerance ability as other schemes mentioned in background section. When less than t secret share calculators are intruded, the system secret key d will not be leaked. Since secret share combiners are added, even all secret share calculators are intruded, the system secret key d will not be leaked also. It can be proved theoretically that attacking secret share combiners cannot obtain the system secret key d; although there are many equations, the rank

of coefficient matrix of the equations is less than the number of variables.

5. The invention can resist a conspiracy attack from the secret share calculator and the secret share combiner, i.e. even when a conspiracy attack is done by a secret share calculator and a secret share combiner, the system secret key d will not be leaked, furthermore, comparing with other schemes, the number of the secret share combiners can be less greatly, for example, when k = 5 and t = 3, the least number of secret share combiners is 2 and the working tasks of the secret share combiner and the secret share calculator are basically equilibrium.

Brief Description of the Drawings

Figure 1 is a schematic diagram illustrating a CA system prototype of ITTC project at US Stanford University;

Figure 2 is a schematic diagram illustrating a secure digital signature system according to the invention;

Figure 3 is a schematic diagram illustrating another secure digital signature system according to the invention;

Figure 4 is a flow chart of the implementation of a secret share calculator; and

Figure 5 is a flow chart of the implementation of a secret share combiner.

Embodiments of the Invention

Figure 2 is a schematic diagram illustrating a secure digital signature system. The system applies RSA algorithm as its basic algorithm.

The system comprises an offline sub-secret-key distributor 21, at least one online task distributor 22, k online secret share calculators 23, m online secret share combiners 24 and an independent online output interface device 25. All these devices can be different common computers or servers. The online task distributor 22 is connected to k online secret share calculators 23 through broadcast channel B1 such as UDP protocol channel. All these devices can be different common computers or servers. The online task distributor 22 is connected to k online sub-secret share calculators 23 through broadcast channel B1 such as UDP protocol channel. The k sub-secret share calculators 23 are connected to m secret share combiners 24 through broadcast channel B2. The m secret share combiners 24 are connected to the output interface device 25

through broadcast channel B3. The offline sub-secret-key distributor 21 is respectively connected to k sub-secret share calculators 23 and m secret share combiners 24 during system initialization or configuration processing (as shown with dot-lines in Figure 2).

The offline sub-secret-key distributor 21 stores a secret key d and does not have network connection with any other systems. The broadcast channels B1, B2 and B3 can be connected physically as one channel or can be independent channels.

The basic principle for realizing the entire system structure is representing a big integer with the sum of several integers, that is, employing the expression: Suppose d_{ji} represents any item from d d_{1i_1} to in the above expression, and the private key for digital signature is d. In the expression, the number of d_{ji} is t, meanwhile all of d, d_{ji} and c_a are positive integers, d_{ji} is a random number to simplify administration. The difference between the above expression and the expression $d=d_1+d_2+d_3+\ldots+d_t$ which is described in the background section is that c_a ($a = 1, 2 \ldots n$) is added to form a new system structure which is secure and easy to administrate.

The processing of sharing secret d in this system structure is completed through two layers of components: one layer of components are composed of secret share calculators 23 and another layer of components are composed of secret share combiners 24. More than one d_{ji} are respectively stored in the secret share calculators 23, and c_a is stored in the secret share combiners 24. In this way, a two-layer secret share structure is formed. Two layers of components respectively store first sub-secret-key d_{ji} and second sub-secret-key c_a. The first sub-secret-key d_{ji} employs two digits as its suffix, among them the first digit j is a sequence number, i.e. device number, of the secret share calculators 23, $j = 1, 2 \ldots k$, and the second digit i is a number of the secret keys stored in a certain secret share calculator 23, $i = 1, 2 \ldots I$. For example, when a secret share calculator 23 stores two items of d_{ji}, the first sub-secret-key respectively are d_{j1} and d_{j2}, meanwhile d_{11} and d_{12} represent two items of first sub-secret-keys stored in the first secret share calculator.

In the two-layer share structure, the second layer secret share combiners start to work only after the first layer secret share calculators have completed calculation. Since the secret share combiners store the sub-secret-key c_a also, they cannot be substituted by other devices.

First, the sub-secret-key is distributed. The distribution operation for the first sub-secret-keys is implemented as follows.

The offline sub-secret-key distributor 21 generates I random numbers d_{ji} for each secret share calculators 23. For a system having k secret share calculators 23, there are k×I first sub-secret-keys

d_{ji}, j = 1, 2, 3, 4 … k. Here, the number of bits in d_{ji} is the half of N. For example, suppose I = 2, the d_{11} and d_{12} are sent to the first secret share calculator 23 through a manner accepted by the key administration, the d_{21} and d_{22} are sent to the second secret share calculator 23, and so on, until the d_{k1} and d_{k2} are sent to the k^{th} secret share calculator 23.

An appropriate parameter t, which means that the system security will not be affected if t-1 secret share calculators 23 are intruded, need to be determined in advance. In order to assure that the system can take t results from the k secret share calculators for complementing operation, t < k should be assured.

The distribution processing of the second sub-secret-keys is as follows. The offline sub-secret-key distributor 21 takes t items from the k×I first sub-secret-keys, and then the c_a can be obtained through a subtraction based on the equation $d = d_{1i_1} + d_{2i_2} + d_{3i_3} + \ldots + d_{ti_t} + C_a$. There are $C_k^t \times i^t$ possibilities in total for taking t items, so the c_a values of the $C_k^t \times i^t$ equations can be obtained. Here, n = $C_k^t \times i^t$ represents combinations, and there are n c_a values and n equation combination representations. Every equation combination representation represents a suffix combination (or referred to sequence number of the variable) of corresponding t first sub-secret-keys d_{ji}, the corresponding suffix of the secret key d_{ji} in this equation is the secret key combinations. Obviously, different first sub-secret-keys in an equation combination are located in different secret share calculators, and an equation combination only relates with the suffixes of the first sub-secret-key d_{ji}, i.e. two digits of j and i, without leaking any information about the sub-secret-key. Suppose every equation combination comprises t items, and digits of each item are the suffixes j and i of a first sub-secret-key d_{ji}, for example, (12, 23, 31) represents an equation combination representation when t = 3.

Before describing the computation procedure for the combinations according to the present invention, first, the combinations with the same device number of secret share calculator are defined as equivalent combinations, and all equivalent combinations are defined as a set of equivalent combinations. For example, (12, 33, 41) (11, 31, 42) (12, 33, 42) are three equivalent combinations. Since tolerance and anti-intrusion are for a machine, for a certain machine, taking which sub-secret-key has no significant affection for successive computation, and setting equivalent combinations is for redundancy. For example, a combination result can be obtained through taking any one of three equivalent combinations mentioned above when there are three normal machines (secret share calculators). Of course, after one of the three equivalent

combinations has been taken, other combinations become meaningless.

The offline sub-secret-key distributor 21 divides all the equation combination representations, the sets of equivalent combinations and corresponding c_a values into groups employing a exhaustive search method according to simplified security condition of the combiners, so that each group has a limited number of equation combination representations. Then m secret share combiners are set according to the number of groups (m), so as to store the equation combination representations of the groups and corresponding c_a values.

Provided that only one combination is taken from one set of equivalent combinations as a representative and then combinations of all representatives are stored into secret share combiners, the correct signature results for each machine combinations can be thus obtained.

The manner of grouping is a key point of the invention. Seen from the secret share combiners 24, only c_a is known and other variables are unknown. The above-mentioned security condition of the combiners, i.e., the number of variables is greater than t for a new equation which is obtained by linear combination of the equations involved in a secret share combiner, is proposed according the expressions and the requirements for system security, in which d_{ji} is a variable.

If the above-mentioned condition is satisfied, the conspiracy attack of the combiners and the share calculators to a system can be thus avoided. However, the condition is too complex to be implemented with a program or procedure. Therefore, a feasible algorithm is needed to implement secure combination.

The secure condition may be simplified, using the particularity of the equations, as a condition that the number of the variables of an equation obtained by linear combination of any two equations in a combiner is greater than t.

Now processing steps of computing and distributing combination represents in the sub-secret-key distributor is described, taking t = 3 and k = 5 as an example.

In the first step, the problem that a secret share calculator has multiple first sub-secret-keys is neglected firstly, all ten kinds of machine combinations are obtained based on C_k^t:

(1, 2, 3); (1, 2, 4); (1, 2, 5); (1, 3, 4); (1, 3, 5); (1, 4, 5); (2, 3, 4); (2, 3, 5); (2, 4, 5); (3, 4, 5).

These ten kinds of machine combinations are the result of selecting arbitrarily three calculators from the five secret share calculators.

In the second step, the obtained ten results are extended, that is, equivalent combinations are obtained for each result, 10 equivalent combination sets are thus formed. When each secret share calculator has two in-machine secret key numbers, each result has 2^t-1 equivalent combinations. All these equivalent combinations are obtained and put in one equivalent combination set, in this way, each equivalent combination set has 2^t equivalent combinations that can be sorted randomly. For example, the equivalent combinations of result (1, 2, 3) with a random sequence are as follow: (11,21,31)(12,21,31)(11,22,31)(12,22,31)(11,21,32)(12,21,32)(11,22,32)

(12,22,32).

In the third step, all the equivalent combination sets are put into a big group. Then they are sorted randomly and prepared to be divided into multiple subgroups.

In the fourth step, an equivalent combination set is taken from the big group sequentially, and then a combination is taken from the equivalent combination set sequentially. Grouping process is implemented through an exhaustive search method according to the simplified security condition, that is, whether the combination can be put into the first subgroup is determined. If so, the combination is put into the first subgroup, and the equivalent combination set is discarded provided that one combination in the equivalent combination set has been put into one subgroup. If the combination cannot be put into the first subgroup, it is returned to the equivalent combination set; and the next equivalent combination of the same equivalent combination set is taken, whether the next combination can be put into the first subgroup is further determined according the simplified security condition. If all equivalent combinations of the same equivalent combination set do not satisfy the simplified security condition, that is, all of them cannot be put into the first subgroup, the same processing is implemented for the second subgroup. If the processing result is not satisfied, then the same processing is implemented for the third subgroup, and so on. After the procedure has been finished, combinations in each non-empty subgroup are taken out, and all combination represents in each subgroup are pre-stored into corresponding secret share combiners through a manner which is accepted by the administrator.

In the fifth step, the fourth step is repeated until all the equivalent combination sets in the big group have been taken into subgroups.

In the sixth step, statistics for the subgroups concluding combinations are taken, and the combinations of a certain subgroup are pre-stored into a secret share combiner.

In the seventh step, some of other combinations that satisfy the security condition are added

into each subgroup with combinations in order to increase redundancy. However, in the adding process, when a combination in an equivalent combination set has been taken into a subgroup, the equivalent combination set will not be discarded.

Under the condition that there are 5 secret share calculators 23 and there are two in-machine secret keys of the first sub-secret-key in each calculator, the computation result after the above processing is as follows.

The nine combinations in the first subgroup are:

(11,21,31)

(11,22,41)

(11,32,42)

(21,32,41)

(12,21,51)

(12,31,52)

(22,31,51)

(21,42,52)

(12,22,32)

The twelve combinations in the second subgroup are:

(11,41,51)

(31,41,52)

(11,21,42)

(12,31,42)

(21,32,41)

(11,22,52)

(12,32,51)

(21,31,51)

(22,42,51)

(32,42,52)

(12,22,41)

(12,21,52)

It can be seen from the above result that only two secret share combiners 24 is enough for five secret share calculators. This is because there are only 10 equivalent combinations in real and now 21 equivalent combinations have been taken into the two secret share combiners, and many redundancies are thus added.

When a solution that 6 secret share calculators are used and each of the secret share calculators stores two numbers of first sub-secret-key in machine is selected, there may be 16 combinations in the first subgroup while there may be 18 combinations in the second subgroup. Two secret share combiners may generate enough redundancy already (the combinations will not be listed here since there are too many combinations).

The number of bits in d_{ji} may be far smaller (maximally one fourth) than that in c_a when the method is implemented. For example, when d is a numeral of 2048 bits, c_a is a numeral of 2048 bits, d_{ji} is a numeral of 500 bits or fewer so as to ensure the calculation speed of the secret share calculators 23 and thus improve the calculation speed of the entire digital signature system.

Although each secret share combiner 24 does not store all the combinations of all

sub-secret-keys d_{ji}, all contents stored in all secret share combiners 24 can guarantee that all d_{ji} combinations for the secret share calculators are involved.

During computation of a digital signature, secret share calculators 23 make ascending power computation for their first sub-secret-keys d_{ji}, the secret share combiners look for matching combinations and then compute them and combine them to a result.

During computation of a digital signature, the task distributor sends the hash value M to be signed to k secret share calculators 23 through broadcast channel B1 with broadcasting mode; when more than t normal secret share calculators, i.e. the secret share calculators that have not been attacked, have received the data, it is assured that the computation result can be obtained.

After having received a task, the secret share calculators make the ascending power computation for all of their first sub-secret-keys. For example, the j^{th} secret share calculator computes the ascending power $M^{d_{ji}}$ after having received the data. This means that each secret share calculator computes the ascending power for all of its first sub-secret-keys. For example, for the first secret share calculator with two first sub-secret-keys, $M^{d_{11}}$ and $M^{d_{12}}$ are obtained first. Then, the $M^{d_{11}}$, $M^{d_{12}}$ and their individual sub-secret-key numbers 11 and 12 (ji), the hash value M to be signed, task number, task distributor number, its machine number are packed and sent to secret share combiners 24 through broadcast channel B2 with broadcasting mode. The process of sending can be implemented just after finishing calculation of $M^{d_{1i}}$, or the result can be sent immediately after it is obtained to improve the efficiency.

The secret share combiners 24 store the received packets according to the task. The received packets are compared with the pre-stored equation combination representations with an exhaustive search method, and t matched combination representations are found and the corresponding c_a are obtained. Then, several matched ascending power results are multiplied, a result R is thus obtained. M^{c_a} can be obtained based on the found c_a. Finally, the digital signature $S = M^d$ will be obtained through multiplying M^{c_a} and R.

The secret share combiners 24 send the signature S to the output interface device 25 in which the correctness of the signature is checked based on the public key.

In the computation procedure above, all broadcasting packets should further comprise: a task distributor number, a number of task that is allocated by the task distributor etc. in order that the system can recognize different tasks and support multi-tasks operation in parallel.

Figure 3 is a schematic diagram illustrating an embodiment of secure digital signature system. The system comprises an offline sub-secret-key distributor 31, five secret share calculators 33 (k = 5), two secret share combiners 34 and an online task distributor 32 that is used as output interface device too. The online task distributor 32 is connected to the five secret share calculators 33 through broadcast channel B1. The five secret share calculators 33 are connected to the two secret share combiners 34 through broadcast channel B2, and also connected to the online task distributor 32 through broadcast channel B1. The offline secret key distributor 31 is connected to the five secret share calculators 33 and two secret share combiners 34 during system initialization and configuration processing.

First, the distributing operation for a sub-secret-key will be described.

An arbitrary number such as 22 is given to the online task distributor 32; a number such as 1, 2, 3, 4 or 5 is given to each of the secret share calculators 33; a number such as 1 or 2 is given to each of the two secret share combiners 34. The system initial value t is set at 3. The private key d is managed by the offline sub-secret-key distributor 31.

The offline sub-secret-key distributor 31 arbitrarily selects 10 random numbers $d_{11},d_{12},d_{21},d_{22},d_{31},d_{32},d_{41},d_{42},d_{51},d_{52}$ which are smaller than d/3 (d/t). Through a mode that is accepted by administration, d_{11} and d_{12} are sent to the first secret share calculator, d_{21} and d_{22} are sent to the second secret share calculator, d_{31} and d_{32} are sent to the third secret share calculator, d_{41} and d_{42} are sent to the forth secret share calculator and d_{51} and d_{52} are sent to the fifth secret share calculator.

The c_a is obtained by making a subtraction from formula $d = d_{1i_1} + d_{2i_2} + d_{3i_3} + \ldots + d_{ti_t} + C_a$. By extending the C_k^t results, the C_k^t equivalent combination sets are obtained and put into a big group.

According the security condition, the combination representations of two subgroups and their c_a values are obtained through an exhaustive search method.

The offline sub-secret-key distributor 31 sends the c_a values of the two subgroups and their equation combination representations to two secret share combiners 34 with the mode that is accepted by the administration. That is, there are 9 equation combination representations and the corresponding 9 c_a values in the first secret share combiner 34 while there are 12 equation combination representations and the corresponding 12 c_a values in the second secret share combiner 34.

After the sub-secret-keys have been sent, the offline sub-secret-key distributor 31 can be shut down.

The computation procedure of a digital signature is as follows:

After having received a signature task and having made the corresponding security check, the online task distributor 32 computes the hash value M to be signed.

The online task distributor 32 defines a task number for the current signature task; the task number should be unique for this task distributor during a period of time (such as two days).

The task distributor number (22), the task number of this task, the hash value M are packed to a packet and broadcasted to the broadcast channel B1.

After secret share calculator j (at least three secret share calculators among all secret share calculators 33 if t = 3) has received the broadcasting packet, it sends an acknowledgement to the task distributor 32 saying that the broadcasting packet has been successfully received.

Then, the secret share calculator j checks the uniqueness of the task. When it is a new task, computation $M^{d_{ji}}$ is made.

The secret share calculator j broadcasts a packet which comprises the number j of itself, the task distributor number 22, the task number, the hash value M, and computation result $M^{d_{ji}}$ to the broadcast channel B2.

The secret share combiners 34 receive the broadcasting packet and put the information with the same task distributor number and the same task number into the same group.

The secret share combiners 34 check whether there are three or more than three results in one group and whether there are three results which can be matched with the stored equation combination representations. If so, corresponding c_a is obtained from the matched equation combination representations. M^{c_a} is obtained based on c_a, then R is computed through multiplying the three results that are matched with the combination representations, finally, the digital signature $S=M^d$ is obtained through multiplying M^{c_a} and R.

The secret share combiners 34 send the task distributor number, the task number and the digital signature $S=M^d$ to the broadcast channel B1.

The task distributor 32 checks whether or not the signature is correct with the public key after receiving the digital signature. If the signature is incorrect, the error processing or warning will be implemented, and if the signature is correct, then the computation task is completed.

All of the specific steps according to the embodiment are suitable to the embodiment shown in Figure 2 also.

The method according to the invention can effectively resist a conspiracy attack from the secret share combiners and the secret share calculators and made when they ally themselves to each other. In the above embodiment, any secret share combiner needs to unite with at least three secret share calculators for obtaining the secret key d, so the method can powerfully resist a conspiracy attack. And only two secret share combiners are needed in the invention.

Figures 4 and 5 are flow charts of the implementation of the secret share calculator in Figure 2 and the secret share combiner in Figure 3, respectively, which show specific applied flows. The implementation employs multithreading technology, i.e. one kind of multitasking parallel processing technique used in a computer operation system. For example, three threads: a task processing program, a monitoring program and an interface program can be used for secret share calculators or secret share combiners. All of the computation tasks are managed by a task queue, and the three threads can access all system parameters (including sub-secret-keys).

The task processing program is specialized for computation. Since computation needs a great amount of time, a single thread is created to implement computation, in order that interaction with users and monitoring data on the network can be continued during computation. The task processing thread uses event synchronization mechanism for waiting, so the CPU time can be saved when there are no computation tasks, and the synchronization can be achieved through employing system events such as EVENT in NT. When the task processing thread is waked up, it scans the task queue to look for the task that should be processed, such as sending data packets that should be re-sent.

The monitoring program is set to guarantee that data on network will not be lost; it monitors broadcasting data on the network. The monitoring thread only makes simple task processing, such as deleting a task or adding a task; and when a new task is coming it wakes up the task processing thread.

The interface program that employs a single thread also is used to process user interface, such as update system parameters and add sub-secret-key etc. without affecting system operation.

The system according to the invention has simple structure, and is easy to implement, moreover, it has the ability of intrusion tolerance. Although total workload for a signature is increased comparing with a common signature processing, the system security is definitely guaranteed. The total time for a signature may be made basically equal to that for a common signature by employing parallel computation and making the number of the bits in d_{ji} far smaller (maximally one fourth) than that in c_a. And it is more important that the system can resist the conspiracy attack from secret share calculators and secret share combiners.

In modern society, enterprises can use the public digital signature facilities. With the method and system according to the invention, a multi-enterprise scheme for public digital signature can be considered. In this scheme, every device stores a set of corresponding data for each enterprise, the task distributor puts the enterprise code into the broadcasting packet to distinguish the enterprises, the secret share calculators find corresponding secret key and implement computation based on the enterprise code, and the computation result is sent to the secret share calculators with the enterprises code etc.

After adding an enterprise code management, the system can become an agent of multiple users and enterprises, and the user or enterprise can control the secret key distributor and task distributor.

With this structure, multiple secret-key issuing centers, multiple task distributors, multiple secret key share calculators and multiple combiners are formed. Consequently, it is a perfect security signature service system.

Drawing

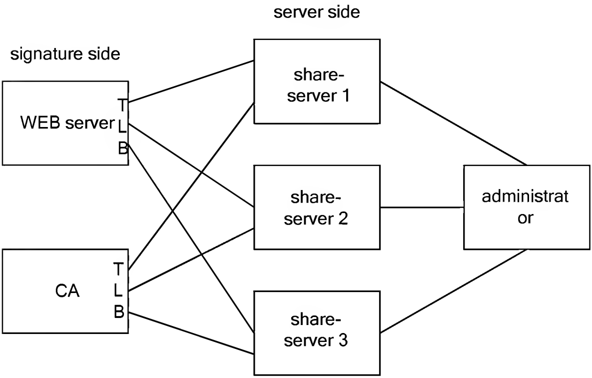


Figure 1

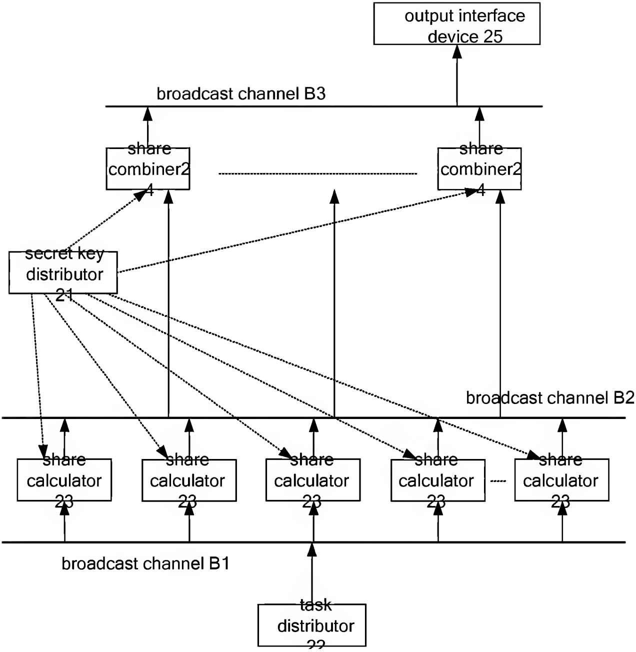
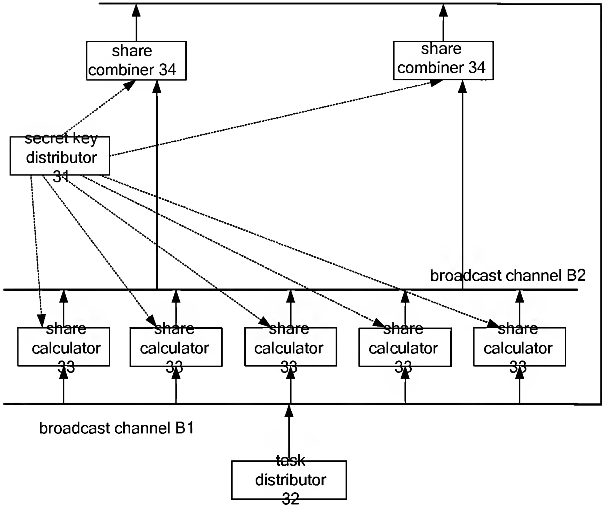
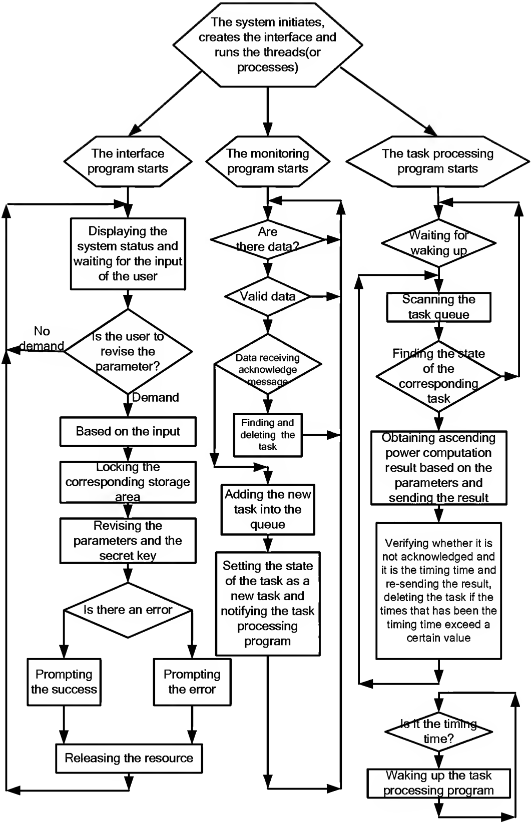

output interface device 25
broadcast channel B3
share combiner24
share combiner24
secret key distributor 21
broadcast channel B2
share calculator 23
share calculator 23
share calculator 23
share calculator 23
share calculator 23
broadcast channel B1
task distributor 22

Figure 2



share combiner 34
share combiner 34
secret key distributor 31
broadcast channel B2
share calculator 33
share calculator 33
share calculator 33
share calculator 33
share calculator 33
broadcast channel B1
task distributor 32

Figure 3



The system initiates, creates the interface and runs the threads(or processes)
The interface program starts
The monitoring program starts
The task processing program starts
Displaying the system status and waiting for the input of the user
Is the user to revise the parameter?
No demand
Demand
Based on the input
Locking the corresponding storage area
Revising the parameters and the secret key
Is there an error
Prompting the success
Prompting the error
Releasing the resource
Are there data?
Valid data
Data receiving acknowledge message
Finding and deleting the task
Adding the new task into the queue
Setting the state of the task as a new task and notifying the task processing program
Waiting for waking up
Scanning the task queue
Finding the state of the corresponding task
Obtaining ascending power computation result based on the parameters and sending the result
Verifying whether it is not acknowledged and it is the timing time and re-sending the result, deleting the task if the times that has been the timing time exceed a certain value
Is it the timing time?
Waking up the task processing program

Figure 4

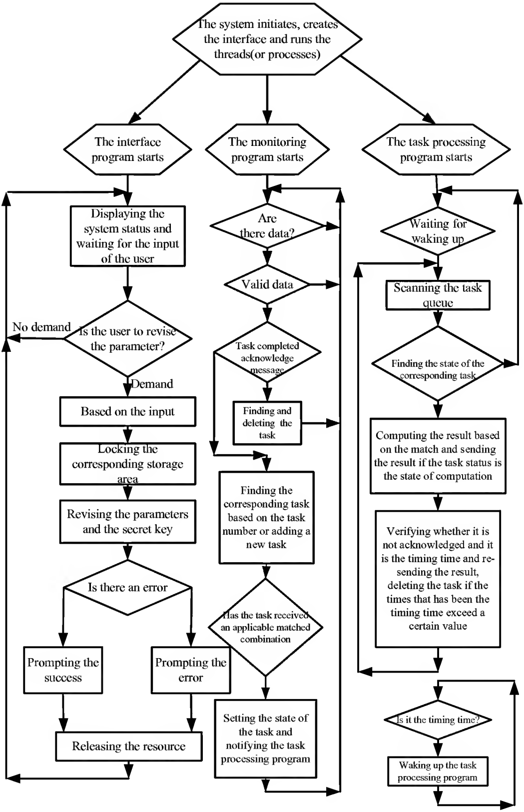

The system initiates, creates the interface and runs the threads(or processes)
The interface program starts
The monitoring program starts
The task processing program starts
Displaying the system status and waiting for the input of the user
Is the user to revise the parameter?
No demand
Demand
Based on the input
Locking the corresponding storage area
Revising the parameters and the secret key
Is there an error
Prompting the success
Prompting the error
Releasing the resource
Are there data?
Valid data
Task completed acknowledge message
Finding and deleting the task
Finding the corresponding task based on the task number or adding a new task
Has the task received an applicable matched combination
Setting the state of the task and notifying the task processing program
Waiting for waking up
Scanning the task queue
Finding the state of the corresponding task
Computing the result based on the match and sending the result if the task status is the state of computation
Verifying whether it is not acknowledged and it is the timing time and re-sending the result, deleting the task if the times that has been the timing time exceed a certain value
Is it the timing time?
Waking up the task processing program

Figure 5